The Effects of Intensive Speech Treatment on Intelligibility in Spanish Speakers With Parkinson's Disease

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ABSTRACT

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The motivation of this study was to examine the effects of intensive speech treatment on the conversational intelligibility of Spanish speakers with Parkinson's Disease (PD). It also aimed at investigating several acoustic variables in the speech of this population. Sixteen speakers with a medical diagnosis of PD participated in this study and their voice recordings were analyzed pre- and post-treatment. The intelligibility measures of transcription accuracy and median ease-of-understanding ratings increased significantly immediately post-treatment and gains were maintained at the one-month follow-up. The acoustic variables of vowel space and voice onset time did not change significantly pre-to-post treatment, whilst the prosodic targets of intensity and mean fundamental frequency increased significantly as a result of treatment. These findings support the implementation of intensive voice intervention to improve intelligibility in Spanish dysarthria. Clinical and theoretical considerations are discussed.

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Chapter 1. Introduction

Parkinson's disease (PD) affects approximately one million individuals in the United States and four to six million people worldwide. It is the second most common neurodegenerative disease, following Alzheimer's disease, and is rated the 14th leading cause of death in the United States (NPF, 2013).

In a study on the incidence of PD in the US, Hispanics were found to have the highest incidence of the disease, followed by non-Hispanic Whites (Van Den Eeden *et al.*, 2003). Moreover, according to the 2010 US Census Bureau report on the languages spoken in the United States in 2007, of the 55.4 million people who spoke a language other than English at home, 62% spoke Spanish (U.S. Census Bureau, 2010). Sixteen percent of the population in 2010 in the US was Hispanic or Latino, representing the largest minority group in the country (Caballero, 2011). In 2012, there were 53 million Latinos living in the United States. This represented a 50% increase since the year 2000 and almost six times the Hispanic population figures in 1970 (Brown, 2014). Of note, the overall population growth in the US was 12% from the years 2000 to 2012. Despite the prevalence of this linguistic group, little is known about Spanish dysarthria and even less, about the effects of speech treatment on intelligibility and the acoustics of this language.

The proposed study was motivated by the need for information regarding characteristics of and effects of treatment for dysarthria secondary to PD in Spanish speakers. It explored speech intelligibility and its relationship with several acoustic variables that have been reported to impact intelligibility in English-speakers with dysarthria. It also explored the potential effects of intensive speech intervention on these parameters and the impact of treatment from the patients' perspective.

1.1. The neurology of hypokinetic dysarthria

Voice and speech deficits are commonly developed in individuals with Parkinson's Disease (Ho, Iansek, Marigliani, Bradshaw, & Gates, 1998; Logemann, Fisher, Boshes, & Blonsky, 1978). Dysarthria is a neurologic motor speech disorder through which the speech musculature displays slow, weak, imprecise or uncoordinated movements (Yorkston, Beukelman, Strand, & Hakel, 2010). Hypokinetic dysarthria is prototypically associated with Parkinson's Disease (PD) and it reflects an underlying pathology in the basal ganglia control circuit.

The basal ganglia are comprised of the striatum, which is composed of the caudate nucleus and the putamen, and the lentiform nucleus, which is formed by the putamen and the globus pallidus. Additionally, there are other areas related to the basal ganglia, such as the substantia nigra and the subthalamic nuclei in the midbrain or mesencephalon, that are also affected by the disease. Anatomically, the basal ganglia control circuit is based on complex interconnections between structures that form multiple loops of information: 1) on the one hand, cortical (especially from the frontal lobe premotor cortex), thalamic, and substantia nigra input connections to the striatum; 2) on the other hand, striatum input to the substantia nigra and the globus pallidus; and 3) input from the globus pallidus to the thalamus, subthalamic nucleus, red nucleus, and reticular formation, which is located in the brainstem. Of note, the primary output pathways in the basal ganglia control circuit have their origin in the globus pallidus.

Physiologically, the circuit regulates muscle tone, controls adjustments in posture during skilled movements, regulates movements in goal-directed tasks, scales movement force, amplitude and duration, and is involved in motor learning, preparation and initiation. Furthermore, the circuit is also responsible for sensorimotor integration and it modulates the auditory feedback necessary in the control for vocalizations. The poor calibration observed in individuals with PD as they overestimate their vocal loudness is, therefore, related to sensorimotor deficits and impairments in the basal ganglia control circuit (Duffy, 2013).

Idiopathic Parkinson Disease (IPD) is a proteinopathy or synucleinopathy; in other words, it is triggered by the misfolding and aggregation of a protein called alpha-synuclein. This protein is contained in the Lewy bodies, filamentous eosinophilic intraneural inclusion granules present in the basal ganglia, brainstem, spinal cord and sympathetic ganglia (Greenberg & Aminoff, 2012). Malfunction of the basal ganglia control circuit is primarily related to chemical imbalances among neurotransmitters (Duffy, 2013); that is, between dopamine and acetylcholine. In IPD, there is a depletion of dopamine in the dopaminergic nigrostriatal system, causing a disturbance between these two antagonistic neurotransmitters.

The basal ganglia control circuit primarily influences speech through its connections with cortical motor areas and has been reported to have an inhibitory function on the cerebral cortex. In healthy individuals, dopaminergic neurons that originate in the substantia nigra inhibit the striatal GABAergic output whilst the cholinergic neurons exert an opposite (i.e., excitatory) effect. In PD, however, the pars compacta of the substantia nigra degenerates, causing overactivation in the indirect pathway and excitotoxicity, an increase in the glutamatergic output from the subthalamic nucleus (Aminoff, 2009; Robelet, Melon, Guillet, Salin, & Kerkerian Le-Goff, 2004). The damping effect exerted by the basal ganglia control circuit is excessive in hypokinetic dysarthria secondary to IPD, which is reflected in its perceptual and acoustic characteristics.

1.2. Overview of the perceptual and acoustic characteristics of hypokinetic dysarthria

Hypokinetic dysarthric speech may be characterized by prosodic insufficiency features, such as monopitch, monoloudness, reduced stress and loudness, variability in rate, short rushes of speech, short phrases, and consonantal imprecision. Of note, the acoustic feature of spirantization (i.e., the production of a plosive or affricate sound with fricative-like, low intensity noise) has been reported as one potential cause for the imprecise articulation of consonants. Additionally, hypokinetic dysarthric speech may be also characterized by perceptual features such as hoarseness, breathiness and voice tremor, even though the latter feature is not so prominent in this type of dysarthria. Acoustic perturbation measures of jitter and shimmer, together with abnormal signal-to-noise (S/N) ratios, have also been reported in individuals with PD but are not always evident in these speakers. Hypernasality as a result of velopharyngeal dysfunction secondary to PD is also a frequent perceptual characteristic in hypokinetic dysarthria (Duffy, 2013).

Vowel working space tends to be centralized and compressed in these speakers and such acoustic feature has been related to the reduction of the second vocalic formant (F2) (Higgins & Hodge, 2002; Rosen, Goozée, & Murdoch, 2008; Tjaden & Wilding, 2004), specifically to a decreased F2 range and slope (Kent, Weismer, & Rosenbek, 1989; Mulligan *et al*., 1994). In order to measure vowel space, new acoustic metrics have been developed that accurately distinguish speakers with PD from healthy individuals, such as the formant centralization ratio (FCR; Sapir, Ramig, Spielman, & Fox, 2010).

These affected speech parameters have been reported to negatively impact intelligibility in speakers with PD (Yorkston *et al.*, 2010), hence compromising their ability to successfully communicate and participate socially (Kent, Miolo, & Bloedel, 1994).

1.3. Intelligibility in dysarthric speech

Intelligibility is defined as the ease of understanding of a speaker's utterance (Laures & Weismer, 1999; Tjaden, Kain, & Lam, 2013). Several factors have been identified as affecting intelligibility, including frequency of errors, degree of consistency between target and actual productions, and familiarity with the speaker and the context (Connolly, 1986). However, the process of assessing intelligibility in disordered speech is complex. In their review of evaluation procedures for intelligibility in pediatric populations, Kent *et al.* (1994) recommended a multidimensional examination approach that includes a variety of assessment tools (e.g., communication efficiency measures and oral productions elicited in different tasks). A multidimensional approach has also been advocated for in the study of intelligibility in dysarthria in adult populations (Hustad, 2006).

The magnitude of the communicative difficulties experienced by a speaker with PD is presumably better reflected through intelligibility metrics that focus on sentences, rather than isolated words (Weismer, 2009). This need to examine intelligibility in more meaningful, real-life contexts (Yorkston, Hakel, Beukelman, & Fager, 2007) has led to the examination of the intelligibility construct in background noise in order to simulate communicative deficits in noisy environments. The use of a speech-in-noise paradigm (Fontan, Tardieu, Gaillard, Woisard, & Ruiz, 2015; Ozimek, Warzybok, & Kutzner, 2010), in which the speech signal is embedded in masking noise at varying signal-to-noise ratios (SNRs), has typically been examined as part of the multidimensional approach to intelligibility studies of dysarthria.

1.3.1. Management of dysarthria

Several studies have attempted to identify the most reliable measures for evaluating intelligibility in disordered speech in both pediatric and adult populations. Hustad (2006) broadly classified those into objective (e.g., listeners' transcriptions) and subjective measures (e.g., listeners' percent intelligibility estimates). In her study on intelligibility measurement in dysarthria, four adults with different degrees of severity of chronic dysarthria secondary to cerebral palsy (CP) were evaluated using two different modalities (i.e., audio-only and audio-visual) and two separate methods (i.e., sentence transcription and percent estimates of intelligibility). Accuracy of transcription was measured by establishing inter-scorer reliability with a second judge, who was blind to the initial scoring. Results revealed higher accuracy (by 11%) for the objective (i.e., transcription) than for the subjective (i.e., percent intelligibility estimates) measure. Furthermore, although a significant main effect for presentation mode was obtained for the audio-visual modality, no significant interactions between modality and speakers or measures were established; that is, the higher intelligibility scores derived from the audio-visual presentation mode were consistent for both intelligibility measures (i.e., percent estimates and transcription) and among all speakers.

Objective and subjective measures of intelligibility (i.e., transcription accuracy vs, intelligibility estimates) are not always combined in studies on dysarthric speech. For example, individuals with dysarthria secondary to multiple sclerosis (N=15) and to Parkinson's disease (N=12) were evaluated for vocal volume, rate and intelligibility in Tjaden and Wilding's (2004) study. The experimental design consisted of three different speaking conditions (habitual, slow and loud) and results were obtained through acoustic analysis and subjective measures of intelligibility (i.e., estimates of intelligibility). Even though estimates of intelligibility in PD were found not to be strongly related to the acoustic changes observed, an increase in scaled intelligibility was found in the speakers with PD in the loud condition, suggesting that increased vocal loudness may enhance listeners' ease of understanding of the speech signal.

McAuliffe, Kerr, Gibson, Anderson, and LaShell's stimulability study (2014) also yielded relevant implications for treatment and dysarthria management. Five New Zealand English-speaking participants with hypokinetic dysarthria secondary to PD were recorded producing 80 experimental phrases in habitual, slow and loud conditions. The order of speaking mode was not varied during the recording. All phrases were semantically anomalous but syntactically correct. A total of 51 listeners participated in the study, for which they were assigned to one of the three speaking conditions. Listeners were instructed to verbally repeat what they heard and a research assistant transcribed their responses in real time. Results revealed that higher intelligibility was obtained for the slow speaking condition, as measured by highest transcription accuracy. As hypothesized in the study, the slow condition may have increased consonant precision, phoneme duration and vowel working space, contributing to the reduction of phonemic ambiguity experienced by listeners. Additionally, fewer lexical boundary errors (LBEs) were also found for the listeners in the slow condition.

These and several more studies have been conducted over the years to achieve a better understanding of intelligibility in individuals with dysarthria. Furthermore, several treatment studies over the past few decades have examined the effects of speech treatments on intelligibility in adults (e.g., individuals with PD) and pediatric (e.g., children with CP) populations.

Some studies of speech treatment for dysarthria have focused on specific treatment techniques to enhance overall communication (e.g., Yorkston, 1996). Helm (1979) investigated the effects of using a pacing board for two weeks on the speaking rate of a single individual with post-encephalitic Parkinson Syndrome and concluded that this method was effective in reducing speech rates and eliminating palilalia because patients could self-monitor their speech. Similarly, Downie, Low, and Lindsay (1981) examined the effects of a portable delayed auditory feedback (DAF) device on the speaking rate of 11 patients with PD. In this study, generalization of the learned skill without the use of the device did not occur.

Other studies on dysarthria management have focused on traditional treatments, which address all speech subsystems: respiratory drive, phonation, articulation, prosody and resonance (Yorkston *et al.*, 2010). Robertson and Thomson (1984) developed an intensive systems approach to treatment for British-English speaking individuals with PD (N=12) that encompassed respiration, voice, articulation, intonation and intelligibility. Treatment was provided for five days a week for two weeks for approximately 3 ½ to 4 hours daily. Significant gains were observed for all of the aforementioned speech areas and were maintained after a three-month follow-up for one of the speech variables (i.e., prosody). Other traditional treatments have also shown promise for improvement of respiration and prosody in dysarthria secondary to PD (Pinto *et al*., 2004). Of note, such studies have primarily focused on dysarthria in American (AE) and British English (BE) speakers.

Speech treatments without the holistic structure of a systems approach, but rather with a specific target of the speech subsystem have also been developed in the treatment for hypokinetic dysarthria in adults, with varying degrees of success. For example, although two of the most common speech characteristics in dysarthria are consonant imprecision and vowel distortions (Darley, Aronson & Brown, 1975; Duffy, 2013), articulation treatment alone, either through normalization of function or compensation of the impairment, has not been frequently implemented in dysarthria treatment (Yorkston *et al.*, 2010). Prosody, however, has been advocated for in the past years. For example, Laures and Weismer (1999) examined the effects of flattening fundamental frequency in utterances produced by non-neurologically impaired speakers, maintaining their temporal and spectral information. Results in word transcription and interval scaling tasks demonstrated that intelligibility was negatively impacted by modifications of the fundamental frequency contour, rendering evidence for the importance of appropriate prosody for sentence intelligibility.

The importance of prosody in contributing to naturalness of speech was also explored in Patel and Alexander (2010). In their study, listeners rated the speech of seven individuals with dysarthria secondary to CP and of seven healthy controls at two speaking rates (habitual and slow) in three prosodic conditions. Intelligibility in both groups (i.e., dysarthric vs. unimpaired speech) was increased when speakers produced utterances in the habitual mode. Traditionally, it has been reported that speakers with dysarthria tend to benefit from slower speaking rates to increase coordination of the speech subsystems (Yorkston *et al.*, 2010); however, at slower rates, prosodic contrasts may be reduced. Patel and Alexander's results indicated that both prosodic and segmental information contribute to intelligibility, hence warranting the development of treatments that improve both aspects of the speech signal.

Whilst intonation is a universal linguistic feature that signals syntax and discourse distinctions through pitch variations (Gussenhoven, 2004), tones are language-specific characteristics that are also determined by different pitch patterns (Kung, Chwilla, & Schriefers, 2014). Changes in pitch at the lexical level (i.e, tones) have been reported to be a contributing factor for intelligibility in Mandarin Chinese (Lee & McCann, 2009). Lee and McCann (2009) investigated the effects of phonation treatment, which targets increasing respiratory support for speech and expanding pitch range for increased vocal fold control, in a within-group design. The two participants were bilingual speakers of Mandarin and English with a diagnosis of severe and mild flaccid dysarthria (respectively) due to a cerebral vascular accident, who received speech treatment in nine sessions for a period of three weeks. Treatment was designed so that task demands increased as treatment progressed, moving from the production of voiceless phonemes to consonant-vowel (CV) syllable combinations. Results revealed positive treatment effects for Mandarin, with increased intelligibility and expanded pitch (i.e., tonal) range; however, no significant increase in intelligibility pre-to-post treatment was observed for English in one of the speakers. A speech treatment, such as phonation treatment, that focuses on expanding pitch range may therefore prove more beneficial for tonal than for non-tonal languages. Results from this study suggest that speech treatment may actually be language-dependent.

Respiratory treatment has also been implemented in the management of dysarthria. The aim of this therapeutic approach is to increase respiratory support in order to consistently produce sufficient levels of subglottal air pressure for speech (Yorkston *et al.*, 2010). Posture control is one of the key characteristics of behavioral respiratory treatment for dysarthrias. Having patients in supine or prone positions is thought to increase subglottal air pressure (i.e., vocal volume), especially if they are not ambulatory (Netsell & Rosenbek, 1985). Despite the importance of adequate respiratory support for speech, respiratory treatments alone have not yielded statistically significant results in the improvement of vocal function in dysarthria (Smith, Ramig, Dromey, Perez, & Samandari, 1995).

The Lee Silverman Voice Treatment (LSVT-LOUD) is the only speech treatment with Level I evidence for improving vocal fold function in PD (Ramig *et al.*, 2001). By implementing a program of maximum vocal effort during sustained phonations and functional speech tasks, LSVT-LOUD is designed to increase subglottal air pressure, improve vocal fold adduction and articulatory movements, and enhance vocal tract configurations (Ramig *et al.*, 2001). The resulting physiological changes have been shown to improve vocal quality (Baumgartner, Sapir, & Ramig, 2001) and articulation (Dromey, Ramig, & Johnson, 1995), expand fundamental frequency range (i.e., prosodic inflections) and enhance resonance (Ramig *et al*, 2001). Findings on self-perceived speech intelligibility as a function of LSVT-LOUD, however, have been equivocal.

Ramig, Countryman, Thompson, and Horii's (1995) study showed significant improvements in pre-to-post intelligibility ratings; however, El Sharkawi et al's (2002) and Ramig, Fox and Sapir's (2004) investigations did not reveal a significant change in perceived speech post-treatment, as measured by speech assessment scales, visual analogue scales and Voice Handicap Index scores (Jacobson et al., 2007). LSVT-LOUD is based on motor learning principles, mainly specificity, saliency, intensity and repetition; therefore, enhancing neural plasticity through an acquired habit of motor routines (Fox, Ebersbach, Ramig, & Shapir, 2012; Kleim, Jones, & Schallert, 2003; Kleim & Jones, 2008).

Ramig *et al.* (1995) compared LSVT-LOUD (Ramig, Bonitati, Lemke, & Horii, 1994) and intensive respiratory (RES) treatments in a group of 45 individuals with PD (33 males and 12 females). LSVT-LOUD focuses on the single target of healthy loudness to address the respiratory and phonatory subsystem deficits that are typically characteristic of dysarthric speech (Fox, Ramig, Ciucci, Sapir, McFarland, & Farley, 2006; Ramig *et al.*, 1994; Ramig *et al*., 1995; Ramig & Dromey, 1996; Ramig, 2000). The intensive respiratory treatment was designed to maximize inspiration and expiration and achieve increased volumes of subglottal air pressure for functional speech through maximum performance tasks (i.e., maximum duration of continuant fricatives /s/ and /f/, maximum inhalation and exhalation, maximum counting on a single breath and sustained intraoral air pressure through the Iowa Oral Performance Instrument [IOPI]). Furthermore, participants were provided with visual feedback on their breathing patterns during some of the tasks. Statistically significant changes pre-to-post treatment were found in the RES group for pause duration during reading, sound pressure level (SPL) during reading, and self-perceived loudness. (The last two variables were statistically significant for females only.)

Research on LSVT-LOUD has also been conducted on other populations, such as adults with non-progressive dysarthria. Wenke, Theodoros, and Cornwell (2010) studied ten speakers with velopharyngeal incompetence (VPI) and non-progressive dysarthria secondary to PD, who were randomly assigned to either LSVT-LOUD or Traditional (TRAD) treatment groups in order to analyze effects of intervention on hypernasality. Participants in the TRAD group received the same frequency and intensity of treatment than the LSVT-LOUD group (i.e., one hour a day, four days a week for four weeks) and completed exercises to improve respiration, phonation, articulation and prosody, depending on their individual needs. Three out of the five speakers in the LSVT-LOUD group demonstrated a significant decrease in perceived hypernasality immediately after treatment, but only one of them maintained the improvement at the 6-months follow-up. Additionally, two of those three participants experienced a reduction in mean nasalance (i.e., the proportion of nasal energy relative to nasal and oral energy during speech). Only one participant in the TRAD group showed a significant decrease in mean nasalance at follow-up.

Sparse research has been conducted on LSVT-LOUD in languages other than English. Whitehill, Kwan, Lee, and Chow (2011) investigated the effects of LSVT-LOUD in 12 Cantonese-speaking individuals with idiopathic PD. Results revealed significant improvements in both vocal loudness and intonation. However, lexical tone was relatively intact, as measured by tone acoustics (i.e., fundamental frequency configurations) and perceptual analysis (i.e., transcription of isolated syllables and identification of error tones in phrases). An adaptation of LSVT-LOUD was implemented in Lemos de Azevedo, Soares de Souza, Marques de Oliveira and Cardoso's (2015) study on prosody in ten Brazilian-Portuguese speakers with PD. Patients received 16 50-minute sessions twice a week (instead of four, as described in the original protocol) and results found increased fundamental frequency and intensity, and decreased measures of duration after intensive speech intervention.

1.4. Acoustic parameters of interest in dysarthric speech:

Several studies have examined the acoustic features of dysarthria in English speakers with PD, from SPL and fundamental frequency (F0) range (Fox, *et al.,* 2006; Ramig *et al.*, 1994; Ramig, *et al.*, 1995; Ramig & Dromey, 1996; Ramig, 2000), to voice onset time (VOT) (Fischer and Goberman, 2010; Flint, Black, Campbell-Taylor, Gailey, & Levinton, 1992; Lieberman *et al.*, 1992) and first moments for plosives and fricatives (Tjaden & Wilding, 2004) to vowel working space and second formant (F2) transitions (Kim, Hasegawa-Johnson, & Perlman, 2011; Sapir, Ramig, Spielman, & Fox, 2010). Few studies, however, have investigated the acoustic parameters characteristic of dysarthria in languages other than English. Ma, Whitehill, and So (2010) investigated the production of intonation (i.e., question-statement) contrasts in 14 Cantonese-speaking individuals with hypokinetic dysarthria secondary to PD. Results revealed that those speakers who obtained low identification accuracy scores from listeners produced questions and statements with reduced F0 and intensity, rendering the identification of the target intonation contrast very challenging. These results are in line with a previous study that showed that acoustic parameters characterizing the speech of Cantonese-speaking individuals with PD (e.g.,roughness, monoloudness, monopitch, breathiness, imprecise consonants, irregular articulatory breakdowns) were similar to those found in English and Japanese speakers with PD (Fukusako *et al.,* 1983; Whitehill, Ma, & Lee, 2003).

Rusz, Cmejla, Ruzickova, and Ruzicka (2011) examined vocal characteristics of 46 native speakers of Czech, 23 of whom were individuals with hypokinetic dysarthria secondary to PD and 23 were healthy adults. Participants engaged in sustained vowel phonation, reading of short phrases and in the production of a short monologue. The speech subsystems of phonation, articulation and prosody were investigated in this study. At the phonatory level, all measures (fundamental frequency standard deviation, shimmer, jitter, noise-to-harmonics ratio and harmonics-to-noise ratio) were statistically significant to differentiate between healthy and hypokinetic dysarthric speech. At the articulatory level, diadochokinetic (DDK) rate and regularity, and vowel space area were measured, with only DDK rate having statistical significance between the control group and group with PD. Of note, vowel space area, albeit not statistically significant, was also reduced in Czech. Non-standard measurements of intensity and F2 slope were also significant, together with reduced melody intonation and decreased intensity variations at the prosodic level.

Similarly, Maruthy and Raj (2014) investigated the perceptual characteristics and intelligibility of hypokinetic dysarthria secondary to PD in eight Malayalam-speaking individuals. Speakers with PD and eight healthy controls produced five semantically anomalous declarative sentences. A group of 20 listeners (10 naïve and 10 experienced listeners) rated the perceptual characteristics and intelligibility of the target sentences together with the degree of listener effort required to understand them. The most salient perceptual features of Malayalam dysarthric speech were reported to be intelligibility, imprecise consonants, distorted vowels, and irregular articulatory breakdowns. Expected results were obtained for the other two dependent variables, intelligibility ratings and listener effort, dysarthric speech being less intelligible and requiring more effort to understand as compared to unimpaired speech.

Few studies have explored characteristics of dysarthria in Spanish. Gamboa *et al*. (1997) examined the acoustic features of dysarthric speech in 41 Spanish-speaking individuals with PD who were treated with dopaminergic drugs and results found increased jitter (i.e., frequency perturbation) and reduced harmonic/noise ratio during sustained vowel phonation, and reduced fundamental frequency range and intensity during sentence production. Similarly, Jiménez- Jiménez *et al*. (1997) examined voice features in 22 individuals with PD who were not treated with dopaminergic medication (i.e., recorded in their OFF phase). Acoustic analyses also revealed increased jitter and reduced harmonic/noise ratio during sustained vowel phonation and reduced fundamental frequency range in sentence production. Increased shimmer was also reported in these speakers.

To the author's knowledge, the only study in Spanish dysarthria secondary to PD that examines, albeit slightly, the relationship between acoustic features and intelligibility is a dissertation by Frass (2003), in which VOT, vowel space and F2 transitions were analyzed in 11 Spanish-speaking individuals with PD and 14 healthy controls. Results revealed significant differences in VOT for all plosives analyzed (even though, the voiced velar plosive was not included in the study). Additionally, a significant difference in vocalic formants was observed for corner vowels /i/ and /u/, as well as for mid-high front vowel /e/. Only a significant relationship between VOT for the voiceless plosive /p/

and intelligibility for single words was found. Even though a slight compression of vowel space was noted, the relationship with speech intelligibility was not examined. Finally, only a mild relationship between formant transition ratios and intelligibility was observed.

The following section describes the acoustic parameter of SPL because of its importance as a primary target in treatment studies on English dysarthria (i.e., LSVT-LOUD), followed by a description of mean fundamental frequency (F_0) and F_0 variability, which represent suprasegmental parameters typically affected in PD. Subsequently, this section details the two acoustic parameters that have been reported to significantly differ (albeit to a different extent) in Spanish dysarthria secondary to PD: VOT and vowel space (Frass, 2003). As limited research has been developed on these variables in Spanish dysarthria, a description of VOT and vowel space in English is provided as basis for the current study.

1.4.1. Sound Pressure Level (SPL)

Hypokinetic dysarthria secondary to PD is associated with reduced vocal loudness (Yorkston *et al.*, 2010), which is related to decreased respiratory drive and limited vocal fold adduction (Ramig *et al.*, 1995). Thus, SPL is another common variable examined in studies that focus on intelligibility in PD. In LSVT-LOUD treatment studies, "healthy vocal loudness" is utilized as the single treatment target, aimed at enhancing vocal fold adduction and respiratory support (Ramig *et al.*, 1995). SPL is thus the primary dependent variable in most LSVT-LOUD research (Fox & Ramig, 1997; Ramig *et al.*, 1995; Ramig *et al.,* 2001; Sapir, Spielman, Ramig, Story, & Fox, 2007). In a comparative study examining 30 patients with idiopathic PD, SPL in dysarthric speech was statistically significantly lower (between 2.0 and 4.0 dB SPL) than in the speech of 14 healthy individuals on various speech and voice tasks (Fox & Ramig, 1997). Increased SPL following LSVT-LOUD has been documented and associated with improved speech function and overall communication. Increases have been maintained for up to 24 months after completion of treatment (Ramig *et al*., 2001).

1.4.2. Mean Fundamental Frequency (F_0) and Variability

Hypokinetic dysarthria is also characterized by underscaling of vocal effort and movement amplitude, which account for the reduction in mean F_0 and pitch range typical of speakers with PD. The striatum in the basal ganglia, cingulate, and prefrontal, parietal, and precentral cortical regions regulate the sense of physical and mental effort (Kurniawan, Guitart-Masip, & Dolan, 2011; Sapir, 2014) whilst the basal ganglia (i.e., internal portion of the globus pallidus, caudate, anterior putamen), subthalamic nucleus and anterior thalamus are involved in scaling and maintaining amplitude in movement (Desmurget, Grafton, Vindras, Gréa, & Turner, 2004). Thus, speakers with PD may evidence a decreased ability to sustain effort when completing motor tasks, such as increasing mean F_0 or expanding pitch range (Sapir, 2014).

Phonation therapy approaches and intensive speech intervention such as LSVT-LOUD have reported gains in mean F_0 and F_0 variability pre-to-post-treatment (Lee & McCann, 2009; Ramig et al., 1994). However, in their comparison between LSVT-LOUD and Respiratory treatments, Ramig et al. (1995) found that mean F_0 during the production of a conversational monologue did not significantly increase as a function of speech intervention for either gender or treatment group.

1.4.3. Voice Onset Time (VOT)

Voice onset time is defined as the period of silence between the release burst of a plosive consonant and the initiation of glottal pulsing (Ansel & Kent, 1992). In typical American English speech, plosives are perceived as voiceless by native speakers when a silent interval of 25msec or more before the start of vocal fold vibration occurs after consonant release in syllable-initial position. When the interval is less than 20msec, a voiced consonant is perceived instead (Klatt, 1975; Lisker & Abramson, 1964). In Spanish, however, VOT is characterized by close to zero, positive values for the voiceless plosives /p/, /t/ and /k/, and negative values (i.e., with voicing beginning before the release burst) for their voiced counterparts /b/, /d/ and /g/.

Several studies have reported that altered VOTs in English speakers with dysarthria contribute to a decrease in speech intelligibility. Research on VOT in PD, however, is sparse and results, variable. In PD, phonatory impairments affecting voicing distinctions have been reported in the literature. In their study on speech and syntactic productions for 40 patients with PD, Lieberman *et al.* (1992) found significant VOT overlap (i.e., merging VOT for voiced and voiceless plosives) for nine patients, who also demonstrated higher error rates for syntactic processing, increased latency of response time, and higher error rates in cognitive tasks. In Forrest, Weismer, and Turner (1989), the voiced plosive /b/ was reported to be significantly longer when produced by nine speakers with dysarthria due to PD than when produced by healthy controls, but no such difference was established for its voiceless counterpart, /p/. Flint *et al*. (1992) determined that VOT in adults with dysarthria due to PD was significantly shorter in duration than in controls. No group differences were observed in Fischer and Goberman's (2010) study examining group and individual VOT and VOT ratio (i.e., VOT independent of articulatory rate) in ten speakers with PD and nine age and gender-matched controls. In CP, more variable and prolonged VOTs have been observed to characterize athetoid and spastic dysarthria (Farmer, 1980), as well as mixed dysarthria (Ansel & Kent, 1992).

1.4.4. Vowel Space Area (VSA)

Greater speech intelligibility is associated with larger vowel space area in dysarthria (Tjaden & Wilding, 2004; Kim *et al.*, 2011; Sapir *et al.*, 2010). Dysarthric speech is typically characterized by a reduction in articulatory working space, which, in turn, results in lower articulatory excursions of the tongue in terms of tongue height (F1) and advancement (F2) (Neel, 2008). In their study on the relationship between intelligibility and vowel contrasts in dysarthria secondary to CP, Kim *et al.* (2011) suggested that decreased speech intelligibility was related to increased vowel overlap, increased variability in first vowel formants (F1), decreased corner vowel space, and decreased mean distance among vocalic segments. Additionally, F2 slopes have been correlated with intelligibility in English dysarthria (Kent *et al.*, 1989; Mulligan *et al.*, 1994) and reduced F2 has been demonstrated to be the most important contributor to the compressed F1-F2 vowel space that is characteristic of dysarthric speech (Higgins & Hodge, 2002; Rosen, Goozée, & Murdoch, 2008; Tjaden & Wilding, 2004).

Sapir *et al.* (2010) proposed a new acoustic metric to evaluate vowel space area in dysarthric speech secondary to PD: the formant centralization ratio (FCR). This measure was designed so that sensitivity to vowel centralization (i.e., compression of vowel space) would be maximized and sensitivity to inter-speaker variability, minimized. That is, the FCR was utilized to reliably distinguish dysarthric from unimpaired speech by detecting reduction in vowel space area typical of dysarthria. Additionally, this new metric was found not to be gender sensitive. Because the first and second formants code most of the spectral information in vowels (Peterson & Barney, 1952), the ratio was formed by the following formula: (F2u + F2A + F1i + F1u) / (F2i + F1A), which includes three cardinal vowels in American English. In order to investigate the reliability and validity of this acoustic metric, Sapir *et al.* (2010) compared 38 speakers with PD to a group of 14 healthy adults in their production of three different phrases. Furthermore, out of the total 38 speakers with PD, 19 speakers received LSVT-LOUD for a month, whilst the other 19 did not receive speech treatment. Findings supported a positive effect of increasing loudness on the expansion of vowel space area, consistent with previous reports of LSVT-LOUD on English vowel articulation (e.g., Sapir, Spielman, Ramig, Story, & Fox, 2007). Results also revealed significant between-group differences for the FCR, suggesting that this new metric was sufficiently sensitive to reliably distinguish the treatment from non-treatment group, as well as the PD from the neurologically healthy group.

Vowel space was also a primary variable explored in Tjaden and Wilding's study (2004) on the acoustic features of hypokinetic and hyperkinetic dysarthria in 12 individuals with PD. Acoustic analysis focused on SPL, F1 and F2 values, F2 transitions, and first spectral moment difference for target fricative and stop consonants. Results revealed reduced vowel working space for individuals with PD as compared to controls in three speaking conditions. Visual inspection of the data further indicated that vowel space tended to increase in the slow condition for nine participants with PD and in the loud condition for three speakers with PD. However, statistical analysis revealed no significant differences in vowel space for any of the three speaking modes for the PD group. It was, therefore, hypothesized that rate reduction techniques could potentially be more effective in maximizing vowel space in speakers with PD, especially those with particularly compressed vowel space areas, than methods targeting vocal volume. Positive effects of a slow over a loud speaking mode on vowel space area were also found in New Zealand English (McAuliffe et al., 2014). Results indicated that vowel space area increased by 12% in the slow condition relative to the habitual condition, but that it decreased by 6% in the loud condition relative to the habitual condition.

Vowel information has been widely examined in the study of dysarthria. Lansford and Liss (2014) investigated different vowel metrics to distinguish between healthy speech and dysarthric speech and among different types of dysarthria in American English (AE). The vowel metrics examined included traditional vowel measurements (e.g., vowel space area (VSA) using the first and second formants of the corner vowels /i/, /æ/, /ɑ/, and /u/ to create an irregular quadrilateral and VSA using the first and second formants of either the vowels /i/, /ɑ/, and /u/ or the lax vowels /ɪ/, /ɛ/, and /ʊ/ to create a triangle), alternate vowel measurements (e.g., FCR) and dispersion and distance vowel metrics. Both spectral and temporal measures of vocalic items produced in phrases were obtained from 45 speakers with dysarthria, with the following subtype categorization: 12 ataxic due to diverse neurological conditions, 12 hypokinetic secondary to Parkinson’s Disease, 10 hyperkinetic secondary to Huntington’s Disease, and 11 mixed flaccid-spastic dysarthria secondary to amyotrophic lateral sclerosis. Twelve healthy adults were also recorded for comparison. Means testing and discriminant function analysis (DFA) were utilized and results displayed that some vowel metrics could be clinically used to detect overall dysarthria but not dysarthria subtype. Centralization of VSA and reduction in mean vowel dispersion in dysarthric speech were expected results. Of note, DFA demonstrated that mean dispersion of front vowels was the most reliable indicator of dysarthric speech, with good sensitivity and specificity, whilst the traditionally used VSA quadrilateral was more sensitive with more severe cases of dysarthria.

Of note, the aforementioned studies focused on AE, which has a complex vocalic system that contains approximately 15 distinctive vowels. Therefore, it is not known whether treatments that expand vowel space in AE will also be as effective in languages with a much more reduced vowel space area (see Figure 1). Studies are needed that explore these variables in other languages, such as Spanish, which stands in stark contrast with its small vocalic inventory of only 5 vowels (Flege, 1991; Schwegler, Kempff, & Ameal-Guerra, 2010).

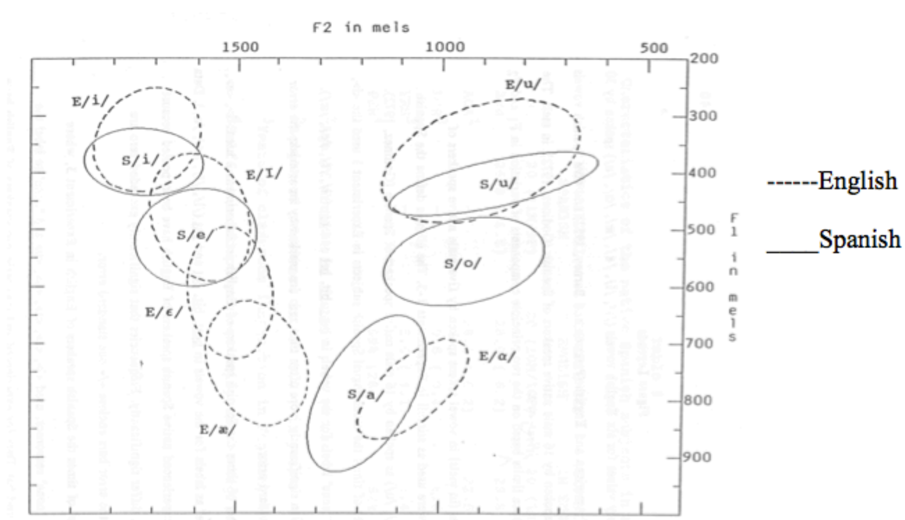


Figure 1. Formant frequency values for six English vowels (/i/, / ɪ/, / ɛ/, / æ/, / ɑ/, /u/) spoken by 30 male native speakers of American English (Peterson & Barney, 1952) and five Spanish vowels (/i/, /e/, /a/, /o/, /u/) spoken by 16 male native speakers of Spanish (Godinez, 1972) in mels. (Flege, 1991)

Additionally, Spanish vowels differ from their English counterparts in their position within vowel space area, the tenseness of the mid vowels (in Spanish /e/ and /o/ are monophthongs and not diphthongs) and the process of vowel centralization in unstressed position, which is reported as nearly absent in Spanish (Menke, 2015).

1.5. Summary

Although research exists on the nature and treatment of hypokinetic dysarthria, few studies have been conducted in languages other than English. Several studies have investigated the impact of dysarthria on intelligibility and acoustic variables, such as vowel working space (Sapir *et al.*, 2010), VOT (Fischer & Goberman, 2010), F2 transitions (Tjaden & Wilding, 2004), and SPL (Fox & Ramig, 1997). Additionally, a myriad of studies have been developed to examine treatment effects on dysarthria in speakers of AE (Ramig *et al.*, 1995; Robertson & Thomson, 1984; Wenke *et al.*, 2010).

Because Spanish is the second most spoken language in the United States (U.S. Census Bureau, 2010) and Hispanics have the highest incidence of PD in the country (Van Den Eeden *et al.*, 2003), there exists a need for information regarding characteristics of and effects of treatment dysarthria secondary to PD in Spanish speakers. LSVT-LOUD is the speech treatment with Level I evidence for improving vocal fold function in PD (Ramig *et al*., 2001). Its efficacy has been demonstrated for AE speakers with dysarthria but few studies have examined its treatment effects in a different language. This dissertation study investigated the intelligibility and acoustics of Spanish dysarthria due to PD and the effects of LSVT-LOUD on these parameters.

1.6. The current study: research questions and hypotheses

The current study addressed the following research questions:

RQ1: Is intelligibility in Spanish speakers with dysarthria secondary to PD reduced when compared to that of neurologically healthy adult Spanish speakers, as measured by transcription accuracy and listeners' intelligibility ratings?

Hypothesis 1: Given the progressive nature of the disease, it was expected that intelligibility in Spanish speakers with dysarthria would be reduced when compared to neurologically healthy adults, as measured by transcription accuracy and listeners' intelligibility ratings (Hustad, 2006).

RQ2: Is speech post-LSVT-LOUD treatment more intelligible than before treatment in Spanish dysarthria secondary to PD, as measured by transcription accuracy and listeners' intelligibility ratings?

Hypothesis 2: Stimulability studies examining the effects of different speaking conditions on intelligibility have associated increased loudness to improved intelligibility in English. McAuliffe et al. (2014) found increased accuracy of phrase transcription when participants with PD (N=5) spoke in the loud condition (60.45%) relative to the habitual condition (45.23%). The authors suggested that such increase was related to listeners' enhanced learning of the acoustic-phonetic properties of loud speech or their improved adaptation to its rhythm. Intelligibility estimates of dysarthric speech have also been found to increase in the loud condition in rating and free-modulus scaling tasks (Tjaden & Wilding, 2004; but see El Sharkawi et al., 2002 and Ramig et al., 2004). Because prosodic word structures are language-specific, lexical segmentation and processing strategies of loud speech in Spanish may differ from English. For example, Spanish is a syllable-timed language (as opposed to a stress-timed language such as English) and is characterized by a large number of polysyllabic words, which typically range between two and three syllables in length (Vitevitch & Rodríguez, 2005). However, it was expected that if LSVT-LOUD increased intensity in conversational speech, syllabic prosodic features (e.g., SPL, mean F_0) would then become more salient, independently of prosodic word structure, making lexical units more prominent and likely contributing to improved intelligibility.

RQ3: Do vowel space, voice onset time (VOT), sound pressure level (SPL), mean fundamental frequency (F_0), and F_0 variability differ in Spanish speakers with dysarthria secondary to PD from neurologically healthy adults?

RQ3.1. If yes, what are the differences?

Hypothesis 3: Vowel space, VOT, SPL, mean F_0 and F_0 variability have been reported to be significantly different in English speakers with dysarthria secondary to PD. As noted above, such differences have been found to contribute to speech characteristics in PD, such as reduced loudness, mono-pitch, and decreased intelligibility. It was predicted that the parameters under study would also differ in Spanish speakers with dysarthria from neurologically healthy adults, although some variables would be more affected by the disease than others. For example, vowel centralization is an allophonic process of Spanish vowels, not a phonological characteristic, as it is in AE. In order words, whilst English vowels may be compressed to /ə/ (e.g., 'apple' [ˈæpəl]) or even disappear into a syllabic consonant (e.g., 'ˈapple' [æpl̩]) in unstressed position, Spanish vowels do not significantly vary from their stressed to unstressed forms (e.g., 'manzana' [manˈθana]). Therefore, reduction in vowel space area may not be as prominent in Spanish dysarthria as in AE dysarthria. Vocal intensity, mean F_0 and F_0 variability, however, respond to decay in movement amplitude originated by the disease (Sapir, 2014); therefore, it was expected that these measures would also be reduced in Spanish speakers with PD.

RQ4: Do vowel space, VOT, SPL, mean F_0 and F_0 variability in Spanish dysarthria change as a function of speech treatment (i.e., following LSVT-LOUD treatment)?

Hypothesis 4: SPL and vowel space have been shown to increase following LSVT-LOUD treatment in AE (Fox & Ramig, 1997; Ramig *et al.*, 1995; Ramig *et al.*, 2001; Sapir *et al.*, 2007). Because LSVT-LOUD focuses on maximum vocal effort, an increase in SPL and mean F_0 was expected after speech intervention in Spanish dysarthria. It is unclear whether the observed expansion in vowel working space in AE following LSVT-LOUD treatment may be replicated in Spanish due to the acoustic differences found between the vocalic segments of the two languages. Specifically, if vowel space was found to be relatively preserved in Spanish dysarthria, it may not significantly expand following LSVT-LOUD treatment.

RQ5: Do self-perceptions of disability in Spanish speakers with dysarthria secondary to PD differ as a function of LSVT-LOUD treatment?

Hypothesis 5: Self-perceptions of disability in English speakers with PD have been reported to improve following LSVT-LOUD treatment. In Ramig *et al.*'s (1995) study, individuals with PD rated significant improvements pre- to post-treatment in 'monotonicity', 'hoarseness', 'intelligibility' and 'frequency of initiating a conversation'. Of note, a significant time by treatment group by gender interaction was found, in which males in the LSVT-LOUD group rated significant improvements in self-perceived loudness. Therefore, it was expected that Spanish speakers with PD would also show higher ratings of their speech function after treatment.

Chapter 2. Methods

2.1 Speakers

Speakers were 16 adults (11 males and 5 females) with a medical diagnosis of PD and no history of speech and language problems prior to the onset of their disease (see Appendix C for speakers' biographical details). They were native speakers of Castilian Spanish, ranging in age from 58 to 82 years (*M* = 70, *SD* = 8). Speakers scored a minimum of 25/30 in the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975; Lobo *et al*., 1999) in their initial evaluation. Their degree of motor severity was categorized as Stages I-III in the Hoehn and Yahr (1967) Scale during their ON phase, as determined by a neurologist. (The ON phase entails the presence of medication resulting in adequate dopamine in the brain, hence allowing the individuals with PD to perform gross motor tasks (e.g., walking) almost normally [Weiner, Schulman, & Lang, 2013]). Similarly, speakers scored no higher than 2 in Part III of the Unified Parkinson Disease Rating Scale (UPDRS) (Goetz *et al.,* 2008) for their motor evaluation and obtained a minimum score of 1 during their ON phase. Presence and severity of hypokinetic dysarthria were determined by consensus of two speech-language pathologists. Hypokinetic dysarthria was operationalized as the presence of some or all of the following speech characteristics: mono-pitch, mono-loudness, reduced stress and loudness, short rushes of speech, inappropriate silences and/or tremor (Rosen, Kent, Delaney, & Duffy, 2006). Speakers' severity of dysarthria was categorized as mild (N=8), mild to moderate (N=2) and moderate (N=5). All speakers were neuropharmacologically stable during treatment. Those who had undergone surgical procedures, such as deep brain stimulation (DBS), were excluded from this study.

Speakers were recruited from UParkinson, a specialized unit for PD research and treatment, at the Teknon Medical Center in Barcelona, Spain. They received intensive speech intervention from the author and all services were free of charge. Recruitment took place in Spain because it provided a better opportunity to establish dialectical homogeneity among the speakers with PD.

A control group of 13 neurologically healthy adults (6 males and 7 females) was also included in the study. Control speakers ranged in age from 37 to 84 years (*M* = 62, *SD* = 12) and reported no history of neurological pathology or communication disorders.

2.2. Design and Procedures

Speakers completed a language background questionnaire at the beginning of their first voice recording session (See Appendix A), together with the Spanish-validated version of the Voice Handicap Index (VHI; Núñez-Batalla *et al*., 2007) to provide information on the impact of their communication disorder on their quality of life and activities of daily living. VHI was chosen because it constitutes an ecologically valid self-report measure (Kapsner-Smith, Hunter, Kirkham, Cox, & Titze, 2014).

Testing (i.e. voice recordings) took place at the Laboratory of Phonetics of the University of Barcelona one month and one week before initiation of treatment, one week after completion of treatment, and after one month post-treatment in order to assess for maintenance of any gains.

2.2.1. Speech Data Collection

Speakers wore an EMW Omnidirectional Lavalier microphone taped to their forehead and secured with a headband. A mouth-to-microphone distance of 8 cm was maintained constant across speakers. The microphone signal passed through a LBS Whirlwind Splitter and a Focusrite Scarlett 2i2 audio interface and was recorded into a digital (ZOOM H4n handy) recorder at a sampling rate of 48kHz with 16 bits of quantization. The input level was not changed throughout the entire study. A calibration tone was generated at the beginning and at the end of each recording session with a KORG LCA-120 Chromatic Tuner for calculation of SPL and noted on a Galaxy CM140 sound level meter (SLM). For each calibration tone, a forehead microphone and the SLM were positioned 8 cm from the mouth of a Styrofoam head, emulating the actual recording conditions for each speaker (Fox & Boliek, 2012).

2.2.1.1. Stimuli

During the testing sessions, speakers were recorded performing a variety of speech tasks. 1. Sentence Repetition. Stimuli were played on a HP desktop computer and through loudspeakers set at a comfortable listening level. The first set of utterances consisted of words containing a syllable-initial plosive consonant (i.e., *pan*, *techo*, *casa*, *barco*, *dados*, *gato* [bread, roof, house, boat, dice, cat]). There were a total of 18 utterances in this task (6 consonants x 3 trials). Such context was chosen because plosives in Spanish can only be produced in syllable-initial position following a silence or a nasal (Martínez Celdrán & Fernández Planas, 2013). The second set of utterances consisted of a carrier phrase (i.e., Diga___ahora [Say___now) and a CVCV word containing a Spanish vowel (i.e., /a/, /e/, /i/, /o/, /u/) in syllable stressed position. There were a total of 15 utterances in this task (5 vowels x 3 trials) 2. Emotional Monologue. Speakers explained a happy day in their lives for approximately 60 sec. The instructions were: 'Ahora quiero que piense en un día o momento feliz en su vida y que lo comparta conmigo' [Now I want you to think of a happy day or moment in your life and share it with me]. For future analysis, the following data were also collected: 1. Picture Description. Speakers described the *Cookie Theft* picture from the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983). Instructions were: 'Me gustaría que me explicara qué sucede en este dibujo' [I would like you to explain to me what is happening in this picture]. 2. Reading. Speakers read a translated version of the Rainbow Passage (Fairbanks, 1960). 3. Vocal exercises. Speakers produced three trials of: maximum duration sustained phonation of /ah/, highest and lowest pitch for approximately five seconds, and alternate motion rates (AMRs) for /pa/ and /pataka/.

Additionally, forced vital capacity (FVC) measures were obtained using a Carolina portable dry spirometer between two and three times at the beginning and end of each recording session and after approximately two minutes of tidal breathing (Ramig *et al.*, 1995; Ramig *et al.*, 2001).

The second pre-test and the two post-test sessions included the same stimuli and tasks. The principal investigator, who delivered speech treatment, did not collect any post-treatment data in order to avoid speakers' familiarity with the clinician (Kapsner-Smith et al., 2014).

2.2.2. Treatment Protocol

Participants engaged in treatment in their ON phase, because motor learning has been found to depend not only on task-training *per se* (i.e., speech treatment exercises) but also on dopamine effects (Beeler *et al*., 2010; Kang & Auinger, 2012). Of note, in mouse models of PD, task-training during the OFF phase has been reported not to be conducive to learning and to lead to performance deterioration over the span of a few days (Beeler *et al*., 2010; Kang & Auinger, 2012; Zhuang, Mazzoni & Kang, 2013).

LSVT-LOUD treatment followed the protocol as described in Ramig *et al.* (1995) and was implemented in four individual and consecutive 60-minute sessions a week for four weeks (i.e., total number of sessions = 16). Within each session, maximum performance tasks (i.e., maximum sustained phonation of 'ah' and maximum fundamental frequency range), and reading of functional phrases constituted the first half of the session. Language tasks, which varied daily, constituted the second half of the session and were constructed following a weekly hierarchical order of language complexity (i.e., single words/phrases, sentences, paragraph and conversational level). Treatment materials were tailored toward each speaker's personal interest in order to increase treatment saliency (Ramig & Fox, 2010).

Augmented feedback was also provided to participants through various instruments (e.g., voice recorder, stop watch, voice mail) in order to enhance speakers' performance. As sensory dysfunction is a common characteristic in PD (Nolano *et al*., 2008), knowledge of results was provided as a substitute for the missing, task-intrinsic feedback that is required to learn the target skill (Magill, 2011). All speakers received daily homework and carry-over tasks. Treatment sessions were videotaped on a Canon

VIXIA HF R500 Digital Camcorder and reviewed by a second speech-language pathologist in order to ensure treatment fidelity (Moncher & Prinz, 1991) and to strengthen the study's internal validity.

2.2.3. Intelligibility Study

The intelligibility study was based on samples from the emotional monologue produced by speakers with PD. Conversational speech was chosen for intelligibility analysis because, although less easily controlled experimentally, it represents a more natural communicative condition and is deemed more likely to reflect the true speech deficits characteristic of speakers with PD than more structured speech tasks (Sapir et al., 2007). Because conversational speech is the 'most socially-valid context' to assess intelligibility (Flipsen, 2006) and, thus, may have more external validity (De Bodt, 2002; Weismer, Jeng, Laures, Kent, & Kent, 2001), using the emotional monologue for this study was considered appropriate to examine intelligibility characteristics and real-life changes in the speakers' communicative abilities post-treatment.

2.2.3.1. Listeners

A total of 21 listeners (nine men and 12 women) participated in the study. The group's average age was 38.1 years (*SD* = 14.2, range = 18-57 years). Listeners were native speakers of Castilian Spanish and reported no history of speech, language or hearing disorders. Additionally, none of them reported having experience with motor speech disorders. They all passed a bilateral pure-tone hearing screening at 25dB at 500, 1000, 2000 and 4000 Hz (American National Standard Institute, 2010) and completed a language background questionnaire prior to their participation in the study.

2.2.3.2. Procedure

Listeners were seated in front of a portable MacBook Pro computer with Mac OSX 10.10.3 and wore Sennheiser HD 280 pro headphones at a comfortable listening level. The following three tasks were conducted to examine speech intelligibility: transcription accuracy, intelligibility ratings, and pre-to-post test comparisons, as described below.

2.2.3.2.1. Transcription Accuracy and Intelligibility Ratings:

Listeners were instructed to produce orthographic (i.e., word-by-word) transcriptions of the recordings on an excel spreadsheet. They were also instructed to provide an estimate of intelligibility for the target utterances using a 9-point Likert scale (i.e., 1 = **Nada** inteligible [Very **un**intelligible] and 9 = completamente inteligible [completely intelligible]). Instructions were (in Spanish): 'Por favor transcriba esta muestra de voz. Las transcripciones son ortográficas (con letras normales). En una escala del 1 al 9, valore cómo de inteligible es la frase que acaba de transcribir' [Please transcribe this speech sample. Transcriptions should be orthographic (regular letters). On a scale from 1-9, rate the intelligibility of this sentence you just transcribed].

The stimuli (N=270) consisted of randomized grammatically correct six-to-nine word utterances (Beijer, Clapham, & Rietveld, 2012). Utterances were selected approximately 20 sec into the speech sample, in order to eliminate potential effects that tend to be associated with the beginning and end of the speech signal (Turner, Tjaden, & Weismer, 1995). Speech samples containing an interrupted or distorted speech signal (e.g., prolonged silences, syllable-repetitions, laughter) were discarded. Three utterances per data collection point for each speaker were included in these tasks (i.e., two baselines, one immediate post-test, and one-month follow-up), totaling 12 utterances per speaker.

Utterances produced by control speakers were also included for later comparison. Control speakers were recorded twice over the course of the treatment study, with a one-month period in-between testing sessions. Thus, six utterances per control speaker were included in these tasks (i.e., three from Time 1 [T1] and three from Time 2 [T2]). Before the selected utterances were embedded in noise, two trained scorers transcribed the speech samples for stimulus verification, with 100% accuracy.

Utterances were embedded in six-talker babble (Simpson & Cooke, 2005; Van Engen & Bradlow, 2007) using Matlab software. This was chosen because background talkers are frequently experienced by listeners (Cullington & Zeng, 2008; Wilson, Abrams, & Pillion, 2003); thus, this type of environmental noise has more ecological validity than other typically used masking procedures, such as white noise (Fontan et al., 2015). Noise was presented in Spanish in order to recreate listeners' daily communication environment. Pre-test utterances were mixed with multitalker babble at 0 dB SNR and noise levels for the post-test and follow-up samples were maintained constant relative to the pre-test noise levels of each utterance in order to examine treatment effects. Multitalker babble has been reported in the literature at various SNRs (Simpson & Cooke, 2005; Van Engen & Bradlow, 2007). Noise levels for these speakers were piloted at -5 dB, -2 dB, 0 dB, +2 dB and +5 dB SNR in order to avoid ceiling and floor effects. A final SNR of 0 dB was selected taking into account the range of severity of the speakers' speech disorder.

2.2.3.2.2. Pre-to-post Test Comparisons

After the transcription and rating tasks, listeners were presented with randomized pairings of utterances from the second baseline and immediate post-test (N=48). Stimulus presentation was counterbalanced so that half of the pairs started with a pre-test utterance and the other half started with a post-test utterance. Listeners were instructed to rate each utterance individually for ease of understanding using a 9-Likert scale and to select the more intelligible utterance within each pair.

Chapter 3. Results

3.1. Data Analysis

Data from 15 speakers with PD and 13 healthy controls were included in the analyses. Data from one speaker with PD (P2) were identified as outliers and were discarded from group analyses.

3.1.1. Intelligibility Measures

Objective and subjective measures of intelligibility were included for analysis (Hustad, 2006). Transcription accuracy scores (i.e., percent words correct) were computed for each utterance and mean accuracy scores were derived for analysis. A liberal scoring approach was implemented (Cannito et al., 2012; Stipancic, Tjaden, & Wilding, in press), by which homophones, phonetically correct misspellings and changes in word order were considered correct. Errors in grammatical morphemes (e.g., 'la chica simpática' [the nice girl] for 'las chicas simpáticas' [the nice girls]) were counted as incorrect responses (Clopper & Bradlow, 2008). Intelligibility ratings were computed and median ratings were calculated.

Descriptive statistics revealed a non-normal distribution of transcription accuracy data; however, the number of observations (N= 5521) was high enough to be considered approximately normally distributed according to the Central Limit Theorem (Rice, 1995). An arcsine transformation of residuals was conducted to normalize the distribution of proportion data; thus, parametric tests could be performed. Therefore, the use of parametric tests was warranted.

Non-parametric tests were conducted to analyze median intelligibility ratings.

In order to ensure reliability, 20% of the utterances were randomly selected and re-measured by the original scorer (intrarater reliability) and by a second scorer (interrater reliability). Intrarater reliability was 100% and a Cronbach's alpha value of .956 was obtained for interrater reliability.

3.1.2. Acoustic Measures

Acoustic analyses were conducted using Praat software (Version 5.3.04; Boersma & Weenink, 2013). A 30-ms window centered at the temporal midpoint of the vocalic segment was obtained for F1 and F2 frequencies through wideband spectrographic displays and LPC spectra (Tjaden & Wilding, 2004). FCR and VSA measurements were calculated via Matlab software. Vowel measurements were averaged across tokens in each speaker. For voiceless tokens, VOT was measured by determining the time lapse from the onset of the initial stop release burst to the onset of vocalic periodicity. Voice-onset times for voiced tokens were measured from the initiation of low amplitude phonation to the onset of the aperiodic stop burst (Rosner, López-Bascuas, García-Albea, & Fahey, 2000). Wideband spectrograms and raw waveforms were utilized in VOT measurements (Fischer & Goberman, 2010). Mean SPL and standard deviation (in decibels), mean F_0 (in Hertz) and F_0 variability (measured as the standard deviation in semitones [STSD]) values were obtained for the individual utterances from the emotional monologues.

An exploration of data descriptives revealed that FCRs, VOT and SPL variables were normally distributed across all data collection points. VSA was normally distributed at baseline only; thus, a log transformation of residuals was performed and parametric tests were conducted. Reliability analyses were conducted and 20% of the original speech samples were randomly selected and re-measured by the original scorer and by a second scorer. Cronbach's alpha was chosen and a value above .91 was obtained for intrarater reliability across all variables and above .85 for interrater reliability.

3.2. Results

3.2.1. Intelligibility Variables

3.2.1.1. Transcription Accuracy

The average transcription accuracy scores for speakers with PD at baseline were significantly lower than for healthy controls, as determined by a one-way ANOVA ($F(1,1737) = 164.5$, p = <.001). The average transcription accuracy scores for speakers with PD were 32.28% (*SD* = 39.62%) for the first pre-treatment and 28.55% (*SD* = 33.64%) for the second pre-treatment sessions. Performance did not differ significantly at baselines (p > .05). Positive effects of intensive speech treatment on intelligibility in Spanish dysarthria were found (*p* = < .001) and a linear mixed model was applied to fully characterize the data. The model consisted of time, gender, age and severity of dysarthria as Fixed Factors.

Transcription accuracy was found to differ significantly across time (p = < .001), with greater accuracy post-treatment. The average transcription scores immediately post-treatment were 71.72% (*SD* = 35.14%) and 66.08% (*SD* = 37.12%) at the one-month follow-up. Further post-hoc pairwise comparisons with Bonferroni correction revealed significant differences from pre-treatment to post-treatment transcription scores (p = < .001) as well as from immediately post-treatment to follow-up performance (p = < .001).

Significant main effects of gender and age on transcription accuracy were also found (p= < .001). Both male and female speakers with PD obtained significantly increased accuracy in transcription scores immediately post-treatment (*M* = 66.65%, *SD* = 36.25% for males; *M* = 81.85%, *SD* = 30.4% for females) and gains were maintained over time for both groups (*M* = 57.95%, *SD* = 39.84% for males; *M* = 82.32%, *SD* = 23.79% for females). However, a one-way ANOVA with post-hoc tests using Bonferroni correction showed a significant decrease in performance at the one-month follow-up relative to immediately post-treatment for the male speakers only, whilst performance remained stable for the female speakers. A Pearson product-moment correlation revealed a statistically significant, albeit small, correlation between transcription accuracy and age ($r = .086$, $n = 3780$, $p < .001$), indicating an increase in transcription accuracy scores with an increase in speakers' age.

A significant main effect for severity of dysarthria was not found (p = .156), indicating no significant differences between the three subgroups of speakers with PD (i.e., mild, mild to moderate, and moderate). Further analyses using a one-way ANOVA and post-hoc tests with Bonferroni correction revealed that the three subgroups performed significantly more accurately immediately post-treatment (p = < .001), suggesting positive treatment effects independently from the severity of the speech disorder. The performance in the three subgroups did not differ significantly at baseline. Only those with moderate dysarthria showed a significant decrease in transcription scores from the immediate post-test (*M* = 49.94%, *SD* = 38.25%) to the one-month follow-up (*M* = 39.7%, *SD* = 41.38%), indicating a decreased ability to maintain treatment gains (see Table 1).

Table 1. Means and standard deviations (in parentheses) for transcription accuracy scores per severity of dysarthria subgroup

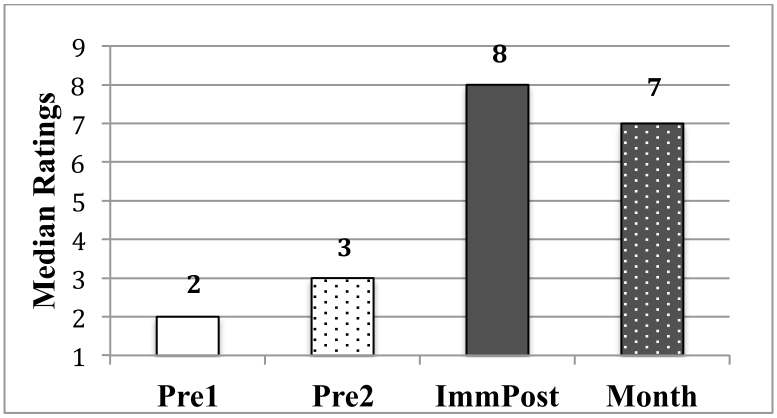
Severity of Dysarthria	**Pre-Treatment 1**	**Pre-Treatment 2**	**Immediate Post-Test**	**One-Month Follow-Up**
Mild	51.5% (41.07%)	46.3% (34.36%)	81.64% (28.86%)	77.61% (26.48%)
Mild to Moderate	20.13% (28.22%)	18.51% (26.42%)	86.48% (22.01%)	85.85% (24.45%)
Moderate	6.46% (19.66%)	4.18% (11.08%)	49.94% (38.25%)	39.7% (41.38%)

Gain scores were computed for speakers with PD and healthy controls. The effect size for treatment (*d* = .738) approximated Cohen's (1988) convention for a large effect size (*d* =. 80).

3.2.1.2. Ratings

A Friedman's test revealed a statistically significant difference in median intelligibility ratings (i.e., perceived intelligibility) across time (χ^2 (3, N=945) = 742.6, p <. 001). Post-hoc analyses were performed using Wilcoxon signed-rank tests with a Bonferroni correction applied, rendering a significance level set at p < .0125. Figure 1 shows median intelligibility ratings for speakers with PD at the four different data collection points.

Figure 2. Median intelligibility ratings of utterances produced by speakers with PD (1 = very difficult to understand and 9 = very easy to understand). Pre1= Pre-Treatment 1; Pre2= Pre-Treatment 2; ImmPost= Immediate Post-Treatment



There were no statistically significant differences in intelligibility ratings between the two baselines (Z = -.801, p = .423). A statistically significant increase was found in median ratings immediately post-treatment (Z = -18.6, p = < .001) and at the one-month follow-up (Z = -17.3, p = < .001). The same pattern was shown when the three subgroups of severity of dysarthria were examined. For healthy controls, no statistically significant difference in performance between T1 and T2 was found (p =. 508).

Pearson product-moment correlations indicated a positive, strong correlation between transcription accuracy scores and intelligibility ratings for the speakers with PD (r = .890, n = 5521, p = <. 001) and for healthy controls (r = .867, n = 1638, p = < .001); that is, as transcription accuracy scores increased, so did intelligibility ratings. Additionally, when the group of speakers with PD was subdivided according to the severity of their speech disorder, positive, strong correlations were maintained for the three subgroups (mild: r = .847, n = 2014, p = < .001; mild to moderate: r = .892, n = 504, p = < .001; moderate: r = .893, n = 1260, p = < .001), suggesting the same pattern of improvement was maintained independently of severity of the speech disorder.

Additionally, pre-to-post test comparisons yielded further evidence of positive treatment effects on intelligibility. Listeners selected post-treatment over pre-treatment utterances 90% of the time.

3.2.2. Acoustic Variables

3.2.2.1. Formant Centralization Ratio (FCR)

Sphericity was assumed for this analysis (χ^2 (5) = 10.525, *p* = .062). A repeated measures ANOVA showed no significant effect for time in vowel production for speakers with PD (*p* = .580), indicating no significant difference in FCR of these Spanish vowels as a function of treatment. The between-subjects factors of gender, age and severity of dysarthria were subsequently and incorporated into the model separately. A statistically significant main effect for gender was found ($F(1,13) = 6.234$, *p* = .027), indicating differences in vowel production between males and females (see Table 2).

Table 2. Means and standard deviations for FCR in male and female speakers with dysarthria

Speaker Group	Pre-Treatment 1		Pre-Treatment 2		Immediate Post-Treatment		Month	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Males (N=10)	.9561	.052	.9695	.036	.9437	.057	.9773	.056
Females (N=5)	.8730	.083	.8807	.069	.9199	.079	.8956	.096

Main effects for age and severity of dysarthria were not found (*p* = .183 and *p* = .149, respectively).

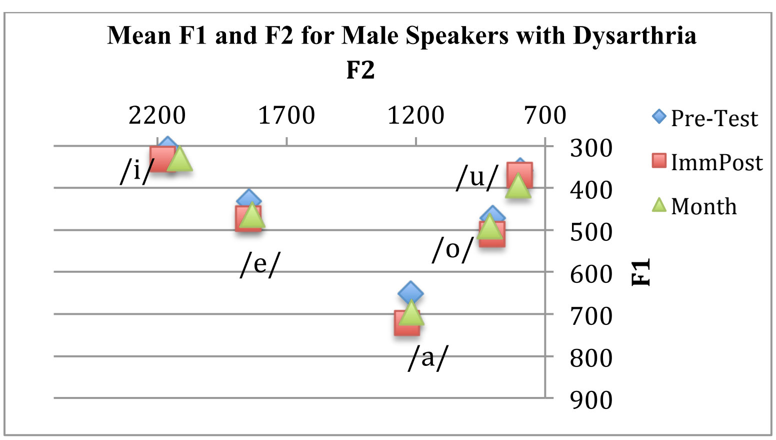
3.2.2.2. Vowel Space Area (VSA)

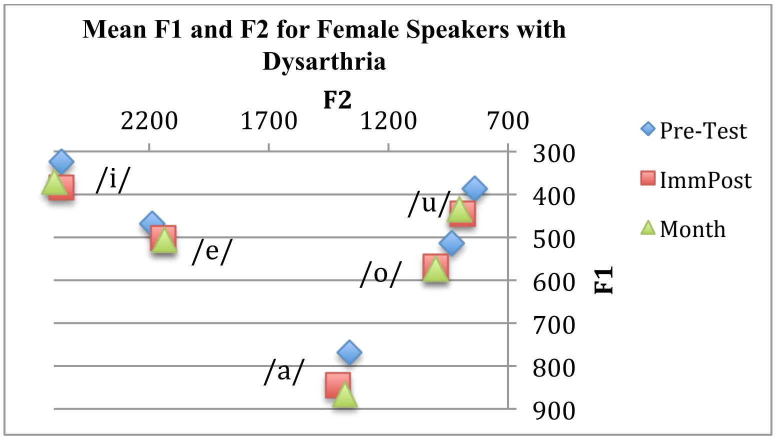
Results for vowel acoustics were replicated with VSA as a dependent variable in order to examine vowel space using an established vowel metric (Lansford & Liss, 2014). A repeated measures ANOVA with a Greenhouse-Geisser correction showed no significant main effect of time on vowel space area in speakers with PD (p= .298). Paralleling the model with FCR, the between-subjects factors of gender, age and severity of dysarthria were separately incorporated into the model, with only gender revealing a statistically significant main effect on vowel production ($F(1,13) = 17.618$, $p = .001$). Visual inspection of descriptive data revealed a higher increase in VSA values in the mild to moderate subgroup immediately post-treatment as compared to the lesser increase in VSA in the other two subgroups (see Table 3).

Table 3. Mean and standard deviation values for VSA in speakers with mild, mild to moderate and moderate dysarthria

Groups	**Pre-Treatment 1**		**Pre-Treatment 2**		**Immediate Post-Treatment**		**Month**	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Mild (N=8)	296066	102179	302979	88148	302270	117976	317570	140819
Mild to Moderate (N=2)	202739	170556	246531	33138	364003	18867	264942	15605
Moderate (N=5)	215052	65515	194109	43920	232760	55743	198660	44874

Figure 3. Mean F1 & F2 for male and female speakers with dysarthria





The vowel plots above (see Figure 2) illustrate a slight expansion of vowel space in dysarthric speech at the two data points post-treatment. This expansion reflects a trend toward an increase in the first formant of low, central vowel /a/, and is indicative of an increase in mandibular excursion.

A one-way ANOVA was conducted to examine differences in vowel acoustics between speakers with PD and controls; differences in FCR and VSA between the two groups were not statistically significant (p = .639 and p = .076, respectively).

3.2.2.3. Voice Onset Time (VOT)

Visual inspection of the data suggested a stable VOT for both voiceless and voiced plosives across data collection points for the speakers with PD (see Table 4). A one-way ANOVA was performed to investigate potential VOT differences between the speakers with PD and healthy controls at baseline. VOT values did not significantly vary between the two groups (p = > .05), except in the production of the voiced, dental plosive /d/ (p = .011), which was characterized by a longer, negative VOT in the control speakers.

Table 4. Means and standard deviations for VOT values in voiceless and voiced plosives for speakers with PD (in seconds)

	Pre-Treatment 1		**Pre-Treatment 2**		**Immediate Post-Treatment**		**Month**	
Voiceless Plosives	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
/p/	.011	.003	.011	.003	.012	.003	.011	.002
/t/	.022	.005	.022	.005	.021	.003	.022	.004
/k/	.035	.011	.035	.012	.033	.006	.034	.006
Voiced Plosives	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
/b/	-.090	.024	-.089	.024	-.095	.023	-.090	.019
/d/	-.084	.020	-.084	.019	-.089	.020	-.085	.022
/g/	-.071	.012	-.071	.013	-.073	.008	-.073	.008

A repeated measures ANOVA found that time did not have a significant main effect in VOT (p = > .05), suggesting that VOT did not change as a function of treatment in Spanish speakers with PD.

The between-subjects factors of gender, age and severity of dysarthria were subsequently incorporated into the model. Only a significant main effect of gender on the production of voiceless, labial plosive /p/ was found (p = .036), with male speakers producing a longer positive VOT than their female counterparts (.012 sec vs .009 sec).

3.2.2.4. Sound Pressure Level (SPL)

Results from a repeated measures ANOVA for SPL during the emotional monologue showed a statistically significant effect for time ($F(3,42) = 11.374$, p = < .001), indicating a positive effect of intensive speech treatment on vocal intensity. No significant main effect for age (p = .160) or gender was found (p = .213), suggesting that both male and female speakers increased conversational SPL post-treatment independently of their age. An average increase of 4.12 dB pre-to-post-treatment was found for the group of speakers with PD. SPL increased an average of 3.99 dB for the male speakers and an average of 4.38 dB for the female speakers pre-to-post-treatment. Table 5 shows SPL means and standard deviations (in decibels) for the group of speakers with PD as well as for males and females.

Table 5. Means and standard deviations for SPL in male and female speakers pre-to-post treatment

	Pre-Treatment 1		**Pre-Treatment 2**		**Immediate Post-Treatment**		**Month**	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Group	65.03	5.11	64.7	3.76	69.15	3.53	68.27	3.73
Males	64.25	5.78	63.22	3.69	68.24	4.01	68.27	4.51
Females	66.58	3.42	67.72	1.39	70.96	1.13	68.28	1.71

A statistically significant main effect for severity of dysarthria was found (F(2,12)= 5.989, p = .016), with the highest increase in SPL observed in the mild to moderate subgroup (63.55 dB at baseline to 71.80 dB immediately post-treatment).

Paired samples T-tests were conducted to compare group means across all data collection points. There was no significant change in SPL at baseline or between the immediate post-treatment and one-month follow-up. In contrast, there was a significant change in SPL between the two pre-treatment sessions and immediately post-treatment (t(14)= -3.669, p = .003 and (t(14)= -5.467, p = < .001, respectively), as well as between those baselines and the follow-up (t(14)= -2.964, p = .010 and t(14)= -3.830, p = .002), suggesting a significant increase in SPL as a function of treatment.

3.2.2.5. Fundamental Frequency (Mean F_0) and variability (STSD)

Mean habitual fundamental frequency was 119.78 Hz (SD = 21.2) for male speakers and 165.57 Hz (SD = 32.3) for female speakers at baseline. Both genders increased their mean F_0 during the monologue task immediately post-treatment (135.12

Hz (*SD* = 24.7) for males and 194.73 Hz (*SD* = 26.4) for females) and at follow-up (137.80 Hz [*SD* = 24.9] for males and 188.15 Hz [*SD* = 20.4] for females). A repeated measures ANOVA with severity of dysarthria as a between-subjects factor showed a statistically significant effect for time for both genders (p = < .001). Severity of dysarthria was significant (p = < .001) for male speakers, with the largest increase (i.e., over 20 Hz pre-to-post-treatment) observed for the mild to moderate dysarthria subgroup. Statistical analysis of fundamental frequency variability (STSD) found a significant effect for time in male speakers ($F(2,58) = 38.412$, $p = < .001$), indicating an increase in STSD post-treatment and, thus, suggesting a decrease in monotonicity. A significant effect for time was also found for females ($F(2,28) = 11.821$, $p = < .001$); however, such change represented a decrease in STSD immediately post-treatment.

3.2.3. Voice Handicap Index (VHI)

Descriptive group data on VHI scores can be found in Table 6.

Table 6. Mean VHI scores and standard deviations for speakers with PD

	Pre-Treatment 1		**Pre-Treatment 2**		**Immediate Post-Treatment**		**Month**	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	36.07	26.7	33.58	23.8	25.27	21.1	27.27	21.4

Paired-sample T-tests were conducted to compare group means across all data collection points. Only the decrease in post-treatment scores relative to pre-treatment scores was statistically significiant ($t(14)= 2.432$, $p = .029$).

There was a statistically significant decrease in the functional subscale of the VHI (χ^2 (3, N=100) = 9.906, p =. 019), indicating an improvement in speakers' perceived functional communication. Post-hoc analyses were performed using Wilcoxon signed-rank tests with a Bonferroni correction applied, rendering a significance level set at $p < .0125$. Only changes from pre-treatment to immediately post-treatment and from pre-treatment to follow-up were statistically significant (p = < .001). No change over time was found for the physical or emotional subscales ($p > .05$).

3.2.4. Forced Vital Capacity (FVC)

A repeated measures ANOVA with a Greenhouse-Geisser correction revealed no significant main effect for time ($p = .637$) on FCV, indicating that treatment-related changes were only observed for speech functions and not for this aerodynamic task.

Chapter 4. Discussion

This study examined the effects of intensive treatment on intelligibility at the conversational level in Spanish speakers with dysarthria secondary to PD. Overall, increasing vocal intensity provided a significant intelligibility benefit to speakers with PD, as measured by transcription accuracy and median intelligibility ratings. This study also investigated the effects of LSVT-LOUD on five acoustic variables (i.e., vowel space, VOT, SPL, mean F_0 and F_0 variability) that have been related to intelligibility in English, providing information on characteristics of Spanish dysarthria pre- and post-treatment. Suprasegmental features in these speakers (i.e., vocal intensity and mean F_0) increased following LSVT-LOUD, whereas segmental variables (i.e., vowel space area and voice onset time) were preserved in the current speech samples and did not significantly differ pre-to-post-treatment.

These results contribute to a better understanding of the effects of loudness on dysarthria secondary to PD in a language other than English. As discussed below, these findings suggest language-independent and language-dependent effects of LSVT-LOUD. Additionally, these data may help speech-language pathologists reach informed clinical decisions when treating Spanish-speaking patients with this motor speech disorder. Specifically, these results support the implementation of LSVT-LOUD when targeting suprasegmental deficits in Spanish speakers with PD.

4.1. *Overall Intelligibility*

The blinded listeners in this study rated the majority of the post-treatment utterances as easier to understand than the pre-treatment speech samples produced by speakers with PD, indicating that Spanish speakers with dysarthria engaging in an intensive program of maximum vocal effort results in a significant improvement in intelligibility. When a 5% change in sentence intelligibility is obtained in settings with adverse listening conditions, this is considered to be clinically meaningful (Stipancic *et al.*, in press; Tjaden *et al.*, 2014). Thus, the intelligibility gain of more than 30% in transcription accuracy and more than 50% in median ratings pre-to-post treatment in the present study's sentences in noise represents a substantial gain in intelligibility for our speakers. Moreover, because transcription accuracy is considered the gold standard measure for assessing intelligibility (Fontan *et al*., 2015; Hustad, 2006; Stipancic *et al.*, in press), the increase in accuracy scores post-treatment is of clinical relevance.

The significant gains in transcription accuracy scores and median ratings were also obtained at one-month post completion of speech intervention. As occurred immediately post-treatment, results from the follow-up revealed that as transcription accuracy scores increased, so did intelligibility ratings. Moreover, as indicated by the VHI functional communciation scores, this increase in conversational intelligibility was related to the improvement in speakers' perceived communicative capabilities. This parallels results found in stimulability studies on English speaking individuals with PD, in which a perceptual benefit to listeners was obtained when speakers performed in a loud speaking condition (McAuliffe *et al.*, 2014; Stipancic *et al.*, in press). Additionally, increased intelligibility has been found after LSVT-LOUD in a typologically different language, with increased accuracy in lexical tone transcription in Cantonese speakers (Whitehill et al., 2011). Thus, the present findings appear to be indicative of a language-independent benefit of increased sound pressure level on intelligibility and provide preliminary support for this treatment technique for Spanish dysarthria.

A main effect of dysarthria severity was not found; suggesting that short-term intelligibility gains are independent of the severity of the speech disorder; however, the speakers with moderate dysarthria showed a significant decrease in transcription accuracy scores at follow-up, indicating a decreased ability to maintain treatment gains. Thus, intensive speech treatment may be more beneficial for those with mild and mild-to-moderate dysarthria in the long-term.

4.2. Acoustics

Several studies on English dysarthria have reported a centralized vowel space in speakers with PD (Sapir et al., 2010) and an expansion of vowel space area secondary to an increase in vocal intensity (Spielman et al., 2000; Turner et al., 1995). The current findings showed that vowel space in Spanish speakers with dysarthria did not differ significantly from that of healthy controls. Moreover, even though a slight expansion as a function of intensive speech treatment was noted upon visual inspection of the data, that increase was not statistically significant. Although this may contrast with findings on

LSVT-LOUD-related increases in vowel space in American English dysarthria, these results are also consistent with previously reported loudness modification effects on vowel production; for example Neel (2009) found a reduction in F2 range but no expansion of vowel space area in five speakers with PD after receiving LSVT-based speech intervention. Similarly, Tjaden and Wilding (2004) reported a slight increase in vowel space with increased loudness in three out of 12 speakers with PD that did not reach significance.

Vowel reduction in Spanish is a phonetic characteristic, not a categorical phonological feature, as it is in English (Cobb & Simonet, 2015); that is, vowels may be produced slightly differently depending on their prosodic position but maintain their spectral identity. Moreover, unstressed vowel centralization as an allophonic process has been reported as nearly absent in Spanish (Menke, 2015) unlike its extensive use in American English. Studies that have found no differences between stressed and unstressed Spanish vowels have primarily utilized read-aloud speech data in their acoustic analysis (Menke & Face, 2010; Ortega-Llebaría, & Prieto, 2010). Of note, however, similar findings have also been reported with more spontaneous speech elicitation tasks (Menke, 2015). Speakers in the present study repeated a carrier phrase containing a word with the target vowel in stressed position. Acoustic analysis revealed no changes in formant frequencies pre-to-post-treatment, indicating that phonemic distinctions among vocalic segments were maintained across time. Therefore, vowel production was acoustically distinct and robust even before the initiation of speech intervention, which could explain why treatment-related changes in vowel space area were not observed. Cross-linguistic comparisons with languages that also possess small vocalic inventories but share acoustic similarities with AE could shed further light on language-dependent VSA characteristics in dysarthric speech. For example, the vocalic system of Catalan consists of eight segments, including /ə/, which represents the centralization of /a/ and /e/ in unstressed positions (Carbonell & Llisterri, 1992); hence, sharing vowel reduction with AE. Arabic, on the other hand, has only three vowels, but they are perceived based on both spectral and temporal cues (Alotaibi & Husain, 2009), which also define AE segments. Future research should examine how languages with these characteristics are affected by dysarthria and whether changes in VSA, if any, are related to intelligibility deficits.

The consonant measure in this study, VOT, did not differ between speakers with PD and the control group (except in the production of the voiced, dental plosive /d/) and it did not change as a function of treatment. These findings are consistent with English studies reporting no VOT differences between speakers with PD (independently of the severity of their speech disorder) and healthy controls (Bunton & Weismer, 2002; Fischer & Goberman, 2010). It has been hypothesized that the lack of VOT differences between these two groups may be caused by articulatory undershoot; that is, the attempt of speakers with PD to compensate for the slow motion of the articulators by reducing the amplitude of their articulatory movements, and, thus, maintaining adequate timing for VOT (Ackermann, Hertrich, and Hehr, 1995; Fischer & Goberman, 2010). This hypothesis, however, may not hold true for speakers with more severe dysarthria, given that they may not be able to engage in such compensation strategies.

The phonatory changes observed were increased SPL and mean F_0 at conversational level. The average increase in vocal intensity in this group of speakers with PD was 4.12 dB pre-to-post-treatment, replicating the results found in English treatment studies that analyzed SPL in monologues (e.g., Ramig et al., 1995; Ramig et al., 2001). An average increase of 8.25 dB SPL was found in speakers with mild to moderate dysarthria. Such increase has been reported in stimulability studies that examine changes in loudness in simple sentences (e.g., Kleinow, Smith, & Ramig, 2001). The present study investigated treatment-related changes in SPL at the conversational level, which involves higher linguistic and physiological complexity. That is, it may have been more difficult for speakers with moderate dysarthria to maintain vocal effort in a monologue task, which requires higher concentration and more dynamic adductory movements at the laryngeal level (Dromey et al., 1995). Therefore, current results suggest that speakers with mild to moderate dysarthria may experience the greatest vocal intensity benefit.

Improvements in mean F_0 and F_0 variability (STSD) as a function of intensive speech treatment were also found, indicating that enhanced prosodic modulations result from this treatment and may also contribute to increased intelligibility (Neel, 2009; Tajden et al., 2014). Mean F_0 significantly increased for both male and female speakers pre-to-post-treatment and from baseline to one-month follow-up, replicating results found in English studies (Ramig et al., 1994; but see Ramig et al., 1995). Similarly, there was a significant increase in the acoustic correlate of monotonicity (STSD) pre-to-post treatment for male speakers only. Inspection of the individual data revealed that the majority of the male speakers with moderate dysarthria increased STSD immediately post-treatment (i.e., they were less monotone), whereas those with mild and mild to moderate dysarthria values showed more variability. Female speakers, on the other hand, showed a significant decrease in STSD post-treatment. This finding could have been affected by a decrease in STSD values in three of the speakers, who also had high STSD pre-treatment. These results are not consistent with findings on LSVT-LOUD-related changes in English (Ramig *et al.*, 1995) and non-English speakers (Whitehill & Wong, 2007). However, they are consistent with a previous report of LSVT-LOUD intervention in Cantonese speakers (Whitehill *et al.*, 2011). These findings provide further evidence for the need to combine quantitative and statistical data with a qualitative description of individual speakers with motor speech disorders because of the heterogeneity of this population (Liss & Weismer, 1992; Lowit-Leuschel & Docherty, 2001; Whitehill *et al.*, 2011).

As stated above, improved intensity and prosodic features have been reported in the literature as contributors to increased speech intelligibility following LSVT-LOUD. Cannito *et al.* (2012) hypothesized that this treatment may also induce changes in the spectral features at the voice source, and that such changes could have a greater impact on intelligibility. In other words, alterations in formant relationships pre-to-post-treatment could result in increased amplitude of the harmonic frequencies beyond the first harmonic or F_0 (Cannito, Buder, & Chorna, 2005). These spectral changes would then lead to more intense formant peaks and to narrower formant bandwidths (Cannito *et al.*, 2012), the latter being associated with increased vowel identification (Hawks, Fourakis, Skinner, & Holden, 1997). Consequently, all the aforementioned changes at the voice source would result in an increased saliency of acoustic cues (Cannito *et al.*, 2008) that would contribute to increased speech intelligibility.

4.3. Summary

This investigation has provided clinical insight into the effects of LSVT-LOUD, the gold standard for treating hypokinetic dysarthria in English, on conversational intelligibility of Spanish-speaking individuals with PD. Our findings indicate that increasing vocal loudness results in improvements in intelligibility in these Spanish speakers, as measured by transcription scores and median ratings. Findings also draw attention to suprasegmental treatment-related changes (e.g., SPL, F_0 and F_0 variability) over segmental contrasts. Thus, results of the present study echo Neel's (2009) suggestion that articulation (including vowel and consonant production) may play a lesser role in speech intelligibility in dysarthria, and that prosody, as well as voice quality, may make greater contributions to intelligibility improvements.

4.4. Limitations and Directions for Future Research

The present study supports the implementation of LSVT-LOUD in Spanish dysarthria for increasing conversational intelligibility. However, future studies need to examine the effects of speech treatment with a larger sample of participants. Additionally, this investigation did not include speakers with severe dysarthria; thus, it remains to be determined whether current findings would also apply to speakers with a more severe dysarthria and whether gains, if any, would be maintained over time past the completion of treatment. So far, positive effects of LSVT-LOUD were found with hypokinetic dysarthria secondary to PD; other types of dysarthria in Spanish speakers should be considered in future studies.

The present study focused on natural speech and on how intensive speech treatment may enhance patients' real-life, conversational intelligibility. However, analyzing conversational speech posed challenges for acoustic measurements. A repetition task for VSA and VOT examination was chosen to ensure a minimum of three trials per target phoneme and to control for the position of vowels and consonants within the speech signal. In order to gain an initial understanding of VSA in Spanish dysarthria and how vowel space may be affected by increases in loudness, vowels were selected in a stressed position within a consonantal context with minimal coarticulation effects. Future analyses will combine the examination of vowels in controlled contexts with their articulation in spontaneous speech in order to assess whether VSA in Spanish varies as a function of task. Of note, however, previous work on vowel production in spontaneous speech by healthy Spanish speakers has revealed results similar to when segments are elicited in their citation form (Menke, 2015). The VOT task was chosen taking into account the characteristics of Spanish plosives. In Spanish, plosive consonants occur only in word-initial position after silence or after a nasal consonant; otherwise, the manner of articulation of plosives changes to that of an approximant phoneme (i.e., thus, without VOT). Consequently, utilizing a task that involved connected speech would have likely compromised the ability to obtain enough samples of each target consonant for VOT measurements.

Finally, the role of the listener in dysarthric speech has received greater attention in the past years. Listener error patterns in Spanish dysarthria are yet to be explored and such investigation could shed light on the cognitive and perceptual strategies that listeners resort to when decoding loud speech (McAuliffe et al., 2014). Similarly, research on bilingual (Spanish/English) listeners could identify cross-linguistic processing strategies in cases of competing languages with differing rhythmic patterns (i.e., syllable- vs. stress-timed). Additionally, an investigation of the relationship between intelligibility, comprehensibility and social participation in Spanish speakers with dysarthria would not only help us better understand the speakers' communicative performance (Fontan *et al.*, 2015), but it would also shed light on the impact of dysarthria and its treatment on the quality of life in this large population of individuals with Parkinson's Disease.

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Appendices

Appendix A. Language Background Questionnaire

Language Background Questionnaire

Please complete this questionnaire as accurately as possible and add any other information that you consider relevant, if necessary

- Participant's name: ________________ Date: __________
- Gender: ____________ Age: ____________ Date of Birth: __________
- Birthplace: ____ (City/Town & Country)
- Occupation: _____________________
- Year diagnosed with Parkinson Disease: ___________

- Language(s) spoken at home during childhood: _________________

    - If more than one language was spoken at home during childhood, please indicate the **approximate percentage** of language use (this should up to 100%) and the **people** with whom you spoke each language:

        Spanish:
        Other(s):

- Language(s) spoken currently at home: ____________________

    - If more than one language is spoken at home, please indicate the approximate percentage of language use (this should up to 100%) and the **people** with whom you speak each language:

        Spanish:
        Other(s):

- Please indicate the place or places where you have lived for the past 10 years:

    1. __________________________
    2. __________________________
    3. __________________________
    4. __________________________
    5. __________________________

- What language do you consider to be your dominant language?
  - Speaking: ________________
  - Listening: ______________
  - Writing: ________________
  - Reading: ____________________
  - Overall daily communication: _______________

- What language do you prefer to use on a daily basis? _____________________

  - If you speak more than one language, please indicate the percentage of each language that you prefer using on a daily basis:

    Spanish: ______________
    Other: _________________

- What language(s) do you speak fluently and can understand with ease?

- Did you ever receive speech and language services before the onset of the disease? YES _______ NO_______
  If yes, please specify (i.e., when, for how long, what speech/language concern was addressed, how was treatment done)

- Have you ever received any speech and language services to treat Parkinson Disease? YES________ NO__________
  If yes, please specify (i.e., when did you begin receiving services, for how long, where, how was treatment conducted)

Appendix B. Cuestionatio sobre Información Lingüística del Participante

Cuestionario sobre Información Lingüística del Participante

Por favor complete este cuestionario de la manera más precisa posible, y añada cualquier otra información que crea conveniente

- Nombre del Participante: ________________ Fecha: __________
- Sexo: ___________ Edad: ___________ Fecha de Nacimiento: __________
- Lugar de Nacimiento: ____
  (Ciudad/Pueblo y País)
- Profesión:
- Año diagnosticado con Parkinson: ____________

- Lengua(s) hablada(s) durante su infancia: _________________

  - Si se habló más de una lengua en su hogar durante su infancia, por favor indique el **porcentaje** aproximado del uso de cada lengua (debe sumar un total de 100%) y las **personas** con las que hablaba cada lengua:

    Español:
    Otra(s):

- Lengua(s) hablada actualmente en su hogar: ___________________

  - Si se habla más de una lengua en su hogar, por favor indique el **porcentaje** aproximado del uso de cada lengua (debe sumar un total de 100%) y las **personas** con las que habla cada lengua:

    Español:

    Otra(s):
- Por favor indique el lugar o lugares de residencia durante los últimos 10 años:

  1. ________________________
  2. ________________________
  3. ________________________
  4. ________________________
  5. ________________________

- Cuál es la lengua que considera dominante actualmente?
  - Al hablar: ________________
  - Al escuchar: ______________
  - Al escribir: ________________
  - Al leer: ___________________
  - Durante la comunicación de cada día: _______________

- Qué lengua prefiere usar en el día a día? ____________________
  - Si habla varias lenguas, qué porcentaje de cada lengua prefiere usas en el día a día:

    Español: _______________
    Otras: ________________

- Qué lengua (s) habla con fluidez y entiende con facilidad? ____________________

- Alguna vez recibió terapia del habla y el lenguaje antes de padecer Parkinson? (e.g., durante su infancia) SÍ ______ NO______
  Si contestó 'sí;, por favor describa (i.e., cuándo, durante cuánto tiempo, qué aspecto del habla y/o el lenguaje le trataron, en qué consistió la terapia) ____________________

  ____

- Ha recibido terapia del habla y el lenguaje para tratar síntomas de Parkinson? SÍ ______ NO_________
  Si contestó 'sí;, por favor describa (i.e., cuándo, durante cuánto tiempo, qué aspecto del habla y/o el lenguaje le trataron, dónde, en qué consistió la terapia)

Appendix C. Biographical details of the 16 speakers with hypokinetic dysarthria

Participant	**Age**	**Sex**	**Hoehn & Yahr stage (1967)**	**YPD**	**Dysarthria Severity**	**Perceptual Impression**
P1	82	F	2.5	7	Mild	Hoarseness, reduced volume
P2	77	M	2.5	6	Moderate	Imprecise articulation, reduced volume, breathiness, monopitch, monoloudness
P3	58	M	2.0	8	Mild	Hoarseness, monopitch
P4	59	M	2	11	Moderate	Fast speech, rapid rushes of speech, imprecise articulation
P5	78	M	3	8	Moderate	Monoloudness, monopitch, reduced volume, imprecise articulation
P6	69	F	2.5	9	Mild	Vocal harshness, reduced volume
P7	80	M	2.5	NA	Moderate	Monopitch, imprecise articulation, reduced volume, monoloudness
P8	77	M	2	14	Mild-moderate	Reduced volume, short rushes of speech, monopitch
P9	58	M	2	15	Mild	monopitch
P10	75	F	2.5	6	Mild	Reduced volume
P11	69	M	2	5	Mild-moderate	Monopitch, monoloudness, reduced volume
P12	79	M	3	17	Moderate	Fast speech, rapid rushes of speech, imprecise articulation, reduced volume
P14	64	M	2	7	Mild	Hoarseness, instances of pallilalia
P15	65	M	3	25	Moderate	Breathiness, reduced volume, monoloudness, monopitch
P16	77	F	2	1	Mild	Reduced volume
P17	62	F	2.5	1	Mild	Reduced volume

Note. Perceptual impressions were determined by two experienced speech-language pathologists. YPD = years post-diagnosis; M = male; F = female; NA = not available